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PATENT SPECIFICATION

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(54) PROCESS FOR THE UNDERGROUND GASIFICATION OF A DEPOSIT

(71) We, INSTITUT NATIONAL DES INDUSTRIES EXTRACTIVES, a Belgian company, of Bois du Val Benoît, Rue du Chéra, 4000 Liège, Belgium, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

5 10 15 Various processes have been proposed for mining coal or lignite by underground gasification. The one which has been most widely developed is the process by filtration of the current of gas between two or more boreholes drilled from the surface.

10 15 Application of this process is, however, at present limited to very thick seams situated not more than two or three hundred metres below ground.

20 25 Application of the process by filtration to the exploitation of thin seams situated at medium or great depth below ground is generally considered to be uneconomical on account of the high cost of drilling deep boreholes and the inferior value of the gas produced.

25 30 35 It is an object of the present invention to overcome these disadvantages and develop a new variation of the process of underground gasification by filtration adapted to deposits consisting of thin seams situated more than 500 metres below the surface.

35 This process has a certain number of characteristics described in detail hereinafter which combine to realise the following three objectives:

40 45 to reduce the cost of the boreholes to a minimum,
to increase the quantity of gasified coal obtained from each borehole and
to achieve optimum stabilization of the energy extracted.

45 Development of the classical methods of working mines has shown that below a depth of the order of 500 to 600 metres, the schists which constitute the major part of coal deposits remain tightly packed even when they have been cracked by

progressive mining. This tightness is demonstrated by the fact that deep layers are generally dry even when they are situated under water bearing formations. It is also demonstrated by the fact at the end of exploitation, gobs situated at a deep level below ground have been able to be used as reservoirs for channeling the fire damp or for storing natural gas.

50 55 In the process according to the invention, this tightness of the terrains of deep deposits is profitably used for underground gasification by injecting air or some other gasifying agent (for example a mixture of air and steam or air, steam and oxygen) the pressure of which is regulated in a cyclic manner so that the gas produced can be conducted to the surface under a minimum pressure of from 15 to 25 bars without the maximum pressure along the circuit exceeding the hydrostatic pressure prevailing in the overlying terrains.

60 65 70 Thus, according to the invention we provide a process for the underground gasification of a deposit of coal or lignite in the form of a plurality of layers situated at a depth of more than 500 metres, consisting of a circulation of a gaseous current with filtration across the layers of fuel, obtained by injecting air or some other gasifying agent through one or more boreholes drilled from the surface and by collecting in one or more other boreholes the gas produced in the deposit by the action of the gasifying agent, underground gasification being carried out under pressure by alternating in a cyclic manner periods of increase in pressure up to a maximum value of 30 to 50 bars with periods of decompression down to a minimum value of 15 to 25 bars, the seam being ignited by a source of heat introduced into one of the boreholes characterised by the combination of a continuous production of gas and a cyclic fluctuation of pressure in the underground gas generator obtained by variation in the rate of flow and the pressure of the injected gasifying agent, the pressure of gas along

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- the whole circuit remaining constantly below the hydrostatic pressure prevailing in the overlying terrain.
- The seam may be ignited by, for example, 5 a gas burner or an electrical heater introduced into one of the boreholes.
- The use of a gasifying agent under high pressure provides the following advantages for the process:
- 10 The possibility of obtaining high rates of gas flow in boreholes of small diameter, hence saving in the cost of the drilling and tubing;
- 15 increase in the coefficients of heat transfer and mass transfer between the gases and solids, whereby it is possible to accelerate the progress of gasification, increase the productivity of the boreholes and improve the overall thermal balance
- 20 by reducing the heat losses across the rocks;
- 25 extension of the zone of action of each borehole, the pressure enabling the gas to overcome resistances to its flow and to cross zones which have caved in or faults in the rock which would constitute insurmountable obstacles for the passage of the stream of gas at low pressure;
- 30 the possibility of directly using the gas produced for supplying a power station operating on a combined gas turbine plus steam turbine cycle, thereby ensuring a high yield of conversion of thermal energy into mechanical energy.
- 35 These alternations of compression and decompression provide the following advantages for the process:
- they enable the zone of action of each borehole to be extended in a direction transverse to the main direction of flow of gaseous flux;
- 40 they facilitate dislodging and breaking down of the fuel, thereby increasing the productivity;
- 45 they give rise to turbulent flow due to penetration of the gas into slits in the rock and into collapsed masses which would otherwise remain outside the active zones.
- The fluctuations in pressure in the 50 underground gas generator, however, should not be accompanied by any substantial fluctuations in the rate of flow of the gas produced because such fluctuations would disturb the operation of the installations using the gas. In the process according to the invention, therefore, continuous production of gas will be combined with cyclic fluctuations of pressure in the underground gas generator,
- 55 60 this pressure fluctuation being achieved by varying the rate of flow and pressure of the gasifying agent injected.
- Underground gasification according to a cycle of variable pressure may also be a 65 means of modulating the electric power supplied by the power station. The increase in pressure in the underground cavities where gasification takes place in fact enables a large quantity of energy to be accumulated which is recovered during the decompression phase. Simply by synchronising the cycle of pressure variation with the cycle of variation in power demand in the distribution network it is possible to increase considerably the flexibility of operation of the power station, the major portion of the energy produced by the gas turbine being used for the compression of air during the hours of low demand and to the production of electricity at peak hours.
- In order to increase the profitability of the underground gasification process, it is important to push to the limits the degree of utilisation of the fuel. In the processes hitherto employed, exploitation ceases when the calorific power of the gas produced falls below 600 to 700 kcal/Nm³ because this value is considered to be the minimum necessary for gas to be capable of industrial utilisation.
- In the process according to the invention, it is provided that a phase of gasification followed by a phase of combustion in situ will take place in each part of the seam. During the latter phase, a substantial excess quantity of air is blown in to bring about combustion of the fuel which has escaped gasification and thus convert this potential energy into sensible heat.
- The same air pressures are used for this combustion phase as for the gasification phase and after having been scrubbed the mixture of air and fumes leaving the boreholes will be reinjected under pressure into the combustion chamber preceding the gas turbine for the purpose of diluting the combustion fumes and returning their temperature to the limit which can be tolerated by the turbine.
- In the same way as gasification, combustion is advantageously carried out in alternating periods of compression and decompression, the cycle of these pressure variations being synchronised with the cycle of variation in the demand for current in the distribution network.
- To ensure successful utilisation of the underground gasification process under pressure, the tubing of the boreholes used for recovering the gasification gas and fumes produced by in situ combustion must not be subject to thermal dilations and contractions which would destroy the tightness of the seal connecting the tubings to the terrain.
- To achieve this result, the boreholes are provided with cooling devices in the form of double walled tubes using circulating water (in accordance with Belgian Patent 130

No. 826 613) or in the form of a detachable tubular device designed to be introduced into the tubing (in accordance with Belgian Patent No. 829,804).

5 These cooling devices operating by thermal exchange across the walls without mixing or contact of the gases and fumes with the circulating water are suitable for stabilising the recovered heat provided that the rates of flow of cooling water are adjusted so as to produce steam under pressure at a suitable temperature for supplying a steam turbine for use in an electricity generating station or for reinjection into the underground gas generator in admixture with the gasifying agent.

10 In the process according to the invention, this adjustment in the rate of flow is achieved by an automatic device actuated by a pressostat.

15 The process according to the invention is further characterised by the fact that gasification of deep layers of the seam is coupled with channelling of the fire damp which is released in the upper part of the seam due to expansion and cracking of the terrain following the process of gasification and combustion of the deep layers. This 20 channelling is carried out by means of one or more boreholes drilled down to the upper stratigraphic layer of the seam.

25 After purification, the rich gas obtained in this way may be used for distribution or stored and reintroduced into the energy cycle of the power station to supply a pilot flame or level out the fluctuations in calorific power of the gasification gas.

30 In the process according to the invention, one and the same network of boreholes for injecting gasifying agent and evacuating gas will be used for successfully exploiting the various layers of the seam.

35 For this purpose, the boreholes will from the start be drilled down to the deepest layer to be exploited in the seam. When exploitation of this first layer has been completed, the lower part of the boreholes will be sealed up and the tubings will be cut off at the level of the next layer immediately above the first, which will then be exploited.

40 The general concept of the process according to the invention will now be described by way of example with reference to the attached drawing in which the lower part represents a section through a coal seam in a vertical plane passing through a series of boreholes for exploiting the seam while the upper part represents schematically the power station above ground for stabilising the gas and steam obtained from exploitation by underground gasification.

45 It will be assumed that it is proposed to

work a virgin seam extending in depth from the stratigraphic level N_1 to the stratigraphic level N_1 .

The preparatory work will consist of producing a network of boreholes for exploitation such as S_1 , S_2 and S_3 drilled down to a sufficiently thick layer situated at the lower stratigraphic level N_1 and of producing one or more boreholes such as S_4 drilled to the upper stratigraphic layer N_2 for collecting the firedamp.

50 If a highly porous layer suitable for collecting and circulating gas is situated on top of the seam, the collecting boreholes will stop in this layer. If no layer of this kind exists naturally, it will be produced artificially by the method of cracking used for petroleum, which consists of ejecting water mixed with sand and wetting agents under a pressure substantially higher than the mean pressure resulting from the weight of the overlying terrain.

55 All the boreholes are equipped with impervious metal tubing which are sealed to the ground by cementing in accordance with known techniques.

60 Each of the boreholes used for exploiting is provided with a cooling device operated on circulating water.

65 In the attached drawing, it is assumed that in the zone between the boreholes S_1 and S_2 exploitation by gasification of the lower layer of the seam has been terminated and that the zone between the boreholes S_2 and S_3 is in the course of 70 gasification. At this stage, atmospheric air raised to the necessary pressure by the compressor 1 driven by the electric motor 2 is injected into the borehole S_2 and at the foot of this borehole is distributed in the 75 seam which is being exploited.

70 Part of the air flows from S_2 to S_3 through a zone still containing a substantial reserve of carbon to be gasified. The poor gas obtained by partial combustion in the presence of an excess of fuel ascends the borehole S_3 to reach the surface at a pressure of the order of 15 to 25 bars and at a temperature of the order of 250 to 300°C. It is scrubbed in the scrubber 3 and burnt, 80 still under pressure, in combustion chamber 4, the air of combustion being supplied by the compressor 5.

85 The remainder of the flow of air injected through the borehole S_2 infiltrates between 85 S_3 and S_1 into the zone of collapsed terrain which remains after termination of the operation of gasification, where it is reheated by contact with the terrain and brings about combustion of the residues of carbon which have escaped gasification. The mixture of air and fumes obtained of this way ascends the borehole S_1 at a pressure of 90 the order of 15 to 25 bars and at a temperature of the order of 250 to 300°C. It 95

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		In continuous operation:		
5	is scrubbed in the scrubber 6 and injected into the combustion chamber 4 to dilute the combustion fumes and raise them to the maximum temperature which can be tolerated at the inlet to the expansion turbine 7.	Power supplied from the steam turbine	+ 58 MW	65
10	The fire damp collected at the top of the seam by the collecting borehole S ₄ is scrubbed in the scrubber 8, compressed in compressor 9, stored in reservoir 10 and used as and when required for supplying a pilot flame and stabilizing the conditions of operation in combustion chamber 4.	Power supplied from the gas turbine	+100 MW	
15	The fumes leaving the combustion chamber enter the turbine 7 at a temperature of the order of 800 to 900°C and leave expanded to a pressure close to atmospheric pressure and at temperature of the order of 400 to 450°C. They then pass through the recovery boiler 11 before being discharged into the atmosphere through the flue 12.	Power consumed by compressor 5	- 10 MW	70
20	The vaporisation circuits of the recovery boiler 11 are supplied by the water pump 13. A second pump 14 supplies the cooling devices inside the boreholes S ₁ and S ₃ . The steam produced by these devices, on recovery of the sensible heat of the gases and fumes, is collected in the collector 15 which rejoins the steam circuit of the recovery boiler 11. All the steam produced is expanded in the turbine 16 and condensed in condenser 17.	Power consumed by compressor 1	- 40 MW	
25	The energy produced by the steam turbine 16 is converted into electricity by the alternator 18. A small part of the energy produced by the gas turbine 7 is used up by the compressor 5, the remainder being converted into electricity by the alternator 19.	Power consumed by pumps and accessories	- 8 MW	75
30	Inasmuch as the circulation of air and gas between the boreholes S ₂ , S ₁ and S ₃ is continuous, one could conceivably operate the compressor 1 by direct coupling to the gas turbine 7.	Power supplied to the network	100 MW	
35	However, it is more advantageous to circulate air and gas between the bore holes S ₂ , S ₁ and S ₃ in accordance with a cycle comprising an alternation of periods of compression to a maximum pressure of the order of 30 to 50 bars with periods of relaxation to a minimum pressure of the order of 15 to 25 bars.	Operation with pressure variations:		
40	With this type of operation, it is possible to modulate to a large measure the quantity of electric energy produced by the power station so that it can be adapted to the fluctuations in demand while maintaining the operation of the gas and steam turbines at their maximum power.	Periods of compression (50% of the time):		
45	The figures given below by way of example are figures which could be obtained in a power station having a nominal power of 100 MW.	Power supplied from steam turbine	+ 58 MW	80
50		Power supplied from gas turbine	+100 MW	
55		Power consumed by compressor 5	- 10 MW	85
60		Power consumed by compressor 1	- 80 MW	
		Power consumed by pumps and accessories	- 8 MW	
		Power supplied to network	60 MW	90
		Periods of decompression (50% of the time):		
		Power supplied from steam turbine:	+ 58 MW	
		Power supplied from gas turbine	+100 MW	95
		Power consumed by compressor 5	- 10 MW	
		Power consumed by pumps and accessories	- 8 MW	100
		Power supplied to network	140 MW	
		WHAT WE CLAIM IS:—		
		1. Process for the underground gasification of a deposit of coal or lignite in the form of a plurality of layers situated at a depth of more than 500 metres, consisting of a circulation of a gaseous current with filtration across the layers of fuel, obtained by injecting air or some other gasifying agent through one or more boreholes drilled from the surface and by collecting in one or more other boreholes the gas produced in the deposit by the action of the gasifying agent, underground gasification being carried out under pressure by alternating in a cyclic manner periods of increase in pressure up to a maximum value of 30 to 50 bars with periods of decompression down to a minimum value of 15 to 25 bars, the seam being ignited by a source of heat introduced into one of the boreholes, characterised by the combination of a continuous production of	105	
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- gas and a cyclic fluctuation of pressure in the underground gas generator obtained by variation in the rate of flow and the pressure of the injected gasifying agent, the pressure of gas along the whole circuit remaining constantly below the hydrostatic pressure prevailing in the overlying terrain.
5. Process according to claim 1, characterised in that in each part of the deposit the phase of gasification is followed by a phase of combustion in situ during which a substantially excess supply of air is blown in to bring about combustion of the fuel which has escaped gasification and to convert this potential energy into sensible heat, the air used for effecting this combustion being blown in at the same pressure as that of the air used for gasification.
10. 2. Process according to claim 1, characterised in that in each part of the deposit the phase of gasification is followed by a phase of combustion in situ during which a substantially excess supply of air is blown in to bring about combustion of the fuel which has escaped gasification and to convert this potential energy into sensible heat, the air used for effecting this combustion being blown in at the same pressure as that of the air used for gasification.
15. 3. Process according to claim 1 or claim 2, characterised in that the boreholes used for evacuating the gasification gas and the fumes produced by in situ combustion are equipped with cooling devices operating on circulating water which protects them against excessive rise in temperature, the heat exchanges taking place across the walls without mixture or contact of the gas and fumes with the circulating water.
20. 4. Process according to claim 3, characterised in that the rates of flow of cooling water are adjusted by means of an automatic device actuated by a pressostat so that by recovery of the sensible heat of the gas and/or fumes steam is produced at a pressure and temperature suitable for supplying a steam turbine, for its use in an electric power station or for its reinjection into the subterranean gas generator in admixture with the gasifying agent.
25. 5. Process according to claims 1 to 4, characterised in that gasification of the deep layers of the deposit, combustion of the fuel which has escaped gasification and production of steam by recovery of the sensible heat of the gasification gas and of the combustion fumes are accompanied by collection of the fire damp which is released in the upper part of the deposit as a result of pressure drop and cracking of the terrain due to the process of gasification and to the residual combustion of the deep layers.
30. 6. Process according to claims 1 to 5, characterised in that production of the poor gases of gasification, of the fumes of in situ combustion, of the rich gases of degasification of the overlying layers and of the steam produced in the cooling circuit in the boreholes is associated with the production of electricity in a power station operating a combined "gas turbine+steam turbine" cycle using all the following together:
35. the poor gases which are burned under pressure in a combustion chamber feeding the gas turbine,
40. the rich gases which are stored or injected into the combustion chamber for feeding a pilot flame and for levelling out the variations in calorific power of the poor gases,
45. the fumes which are used for diluting and cooling the fumes of combustion of the gas in the combustion chamber and the steam which helps to feed the steam turbine.
50. 7. Process according to claim 6, characterised in that the alternations of periods of compression of gasification gas with periods of decompression of gas and fumes produced during the phases of gasification and of in situ combustion are synchronised with the fluctuations in demand for current in the electric network, the periods of compression of the gasifying agent coinciding with the periods of low demand in the electric network while the periods of decompression of the underground gas generator are in phase with the periods of peak consumption of the electric supply so that the energy accumulated by compression of the gas in the underground cavities during periods of low demand can be restored to the network in the form of electric energy during peak periods.
55. 8. Process for the exploitation of a deposit of coal or lignite by gasification and combustion in situ as described herein and represented in the appended drawing.

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